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# U-Pb zircon age of volcaniclastic layers in Middle Triassic platform carbonates of the Austroalpine Silvretta nappe (Switzerland)

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*Key words:* U-Pb-age, chronostratigraphy, Early Ladinian, Austroalpine nappes, Canton Graubünden.

ABSTRACT

We present precise U-Pb age determinations from two volcaniclastic layers within Middle Triassic carbonates in the Upper Austroalpine Silvretta nappe near Davos (Switzerland). The two volcaniclastic layers were dated using annealing-leaching techniques and yielded ages of 240.91 ± 0.26 Ma (Prosanto Formation) and 239.89 ± 0.21 Ma (Altein Formation), respectively. The high resolution ages allow comparison of the Upper Austroalpine record of the Ducan with sections in the Southern Alps. The upper Prosanto Formation is, thus, equivalent to the middle part of the Buchenstein Formation (Middle Pietra Verde, Earliest Ladinian), and the Altein Formation is equivalent to the upper part of the Buchenstein Formation in the section with the Global boundary Stratotype Section and Point (GSSP) for the base of the Ladinian (Bagolino, northern Italy). This study demonstrates that we can use precise, accurate and carefully intercalibrated U-Pb zircon ages from volcaniclastic layers to infer the stratigraphic position of their host sediments on zone level. The older volcaniclastic layer (240.91 ± 0.26 Ma) allows a precise age determination (earliest Ladinian) for the marine vertebrate beds in the upper Prosanto Formation.

ZUSAMMENFASSUNG

Hoch auflösende U-Pb-Altersbestimmungen an zwei vulkanoklastischen Lagen in mitteltriassischen Karbonaten der oberostalpinen Silvretta-Decke bei Davos (Schweiz) ergeben präzise Alter von 240.91 ± 0.26 Ma (Prosanto-Formation) und 239.89 ± 0.21 Ma (Altein-Formation). Die genauen Altersbestimmungen erlauben einen fundierten Vergleich der oberostalpinen Mitteltrias des Ducangebiets mit Profilen der Südalpen: Die obere Prosanto-Formation entspricht der mittleren Buchenstein-Formation des Frühesten Ladins (Mittlere Pietra Verde), die Altein-Formation dem oberen Teil der Buchenstein-Formation im Typusprofil (GSSP) der Ladin-Basis (Bagolino, Norditalien). Die Studie zeigt, dass präzise und gut kalibrierte U-Pb-Zirkon-Alter von vulkanoklastischen Lagen zur Bestimmung der stratigraphischen Position der umgebenden Gesteine auf Zonen-Bereich geeignet sind. Der ältere vulkanische Tuff erlaubt mit 240.91 ± 0.26 Ma (Frühestes Ladin) erstmals eine genaue Alterseinstufung der marinen Wirbeltierfauna der oberen Prosanto-Formation.

## Introduction

Triassic sediments form the major part of the Austroalpine and South Alpine units of Austria, south eastern Switzerland, and northern Italy and have been intensively studied and discussed since the classical works by geologists of the "Kaiserlich-königliche geologische Reichsanstalt" (Geologische Bundesanstalt) in Vienna at the end of the 19th century. Anisian/Ladinian carbonate platforms and basins characterize the Austroalpine and South Alpine realm. The basins are filled with siliciclastic and carbonate sediments, which often are organic carbon-rich and indicate dysoxic to anoxic conditions. Some of these basinal sediments are classical fossil lagerstaetten with extraordinary well-preserved marine fish and reptile fauna (Bürgin et al. 1992). The basinal units seem to be heterochronous, but a general deepening trend between the different basins from west to east, respectively north to south towards a hypothetical Vardar-Meliatha-Hallstatt Ocean is observed (Dercourt et al. 2000). The deeper and more open-marine basins contain a rich ammonoid and conodont fauna and a detailed biostratigraphy has been established (Tollmann 1976, Brack & Rieber 1993, Brack et al. 2005). The more landward or proximal basins were restricted from open seawater and usually do not contain index fossils. Due to the lack of age data from these more restricted sedimentary units, conclusions on the tectonic and paleoceanographic evolution, and the large scale palecology of the different environments within the Austroalpine and South Alpine area during the Middle Triassic remain speculative.

We present U-Pb zircon age data from two volcanic ash layers that occur within finely laminated intraplatform basinal limestones in the Upper Austroalpine Silvretta nappe (Graubünden, Switzerland), and more precisely, in the Middle

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Triassic Prosanto Formation and 80 m higher in the section, in the Altein dolomite platform, respectively. Even though index fossils seem to be almost absent, high-precision U-Pb data from zircons prepared by thermal annealing–chemical leaching techniques (Mattinson 2005) allow for the first time a correlation at substage and, respectively, zone level intervals between the Silvretta nappe and corresponding sections in a different Austroalpine unit (Lechtal nappe) in the Northern Calcareous Alps and with units in the Southern Alps.

## The Triassic of the Eastern Alps

Triassic sediments form the most important lithological units in the Eastern Alps between Vienna at the eastern end, and the Silvretta nappe in eastern Switzerland (Graubünden). They form an important part of the Lechtal nappe (western unit of the Northern Calcareous Alps), at the border between Austria and Switzerland (Fig. 1). In Graubünden, a complex of allochthonous units of basement rocks and their Mesozoic sedimentary cover form the Upper and Lower Austroalpine nappes (Trümpy 1980). Despite the low metamorphic grade and the high degree of tectonic deformation, regional stratigraphic studies have allowed the reconstruction of composite lithostratigraphic columns (Furrer 1985), but proposed palinspastic or paleogeographic reconstructions are largely hypothetical (Frank 1986). Age diagnostic fossils such as ammonoids or conodonts are rare. The Triassic in the Upper Austroalpine nappes of Graubünden is up to 2000 meters thick, whereas the same formations in the Lower Austroalpine nappes show a reduced thickness of just a few hundreds of meters. The thickest stratigraphic sequences are exposed in the Silvretta nappe near Davos and in the S-charl nappe south of Zernez, belonging to different Upper Austroalpine tectonic units.

The Middle and Late Triassic sediments of the Austroalpine nappes have strong analogies to time equivalent strata in the South Alpine areas, interpreted to have formed a common ancient domain, the so called “Alpine Triassic” on the continental shelf along the north-western Tethys. The Upper Austroalpine nappes of Graubünden seem to fit best with the north-western Northern Calcareous Alps in Vorarlberg (Western Austria) and the western Southern Alps in Ticino (Southern Switzerland) and Lombardy west of the Grigna mountains (Northern Italy).

## The studied stratigraphic section in the Upper Austroalpine Silvretta nappe

The most complete section of the studied area is exposed in the Ducan region between Davos and Bergün (Fig. 2; Eugster 1923, Eichenberger 1986, Furrer et al. 1992). Gneisses and amphibolites of the metamorphic basement of the Silvretta nappe are covered by Permian volcanic and volcaniclastic rocks. The fine grained and well sorted siliciclastics in the upper part of the Chazforà Formation display fluviatile sedimentary structures, whereas the Fuorn Formation represents tidally influenced shallow marine deposits of probably Early Triassic age. Above an alternation of dolomites and sandstones in the Gracilis Member of the Ducan Formation with the Anisian crinoid *Dadocrinus gracilis*, the nodular limestone of the Brachiopodenkalk Member represents the first open marine sediments. Brachiopods as *Tetractinella trigonella, Spiriferina mentzeli, Decurtella decurtata, Coenothyris vulgaris* and crinoids are common. Rare ammonoids and conodonts suggest a Late Anisian age (Ouwehand 1984). The Trochitendolomite is the upper member of the Ducan Formation, rich in crinoid sclerites. Cornieules indicating a regression at the base of the S-charl Formation are overlain by a lagoonal sequence of shallowing upward carbonate cycles. The overlying Vallatscha Formation consists of dolomitic carbonate sands with a shallow marine, mainly lagoonal fauna and flora (dasycladacean algae).

Thin bedded dark lime- and marlstones with slumping structures and layers of flat pebble conglomerates and calcareous turbidites are typical for the Prosanto Formation. This interval contains several beds with well preserved vertebrates, mainly actinopterygian fish and marine reptiles (Bürgin et al. 1991, Furrer 2004). Until now, approximately 20 actinopterygian taxa and three reptilian (nothosaurian, pachypleurosaurian, and protorosaurian) have been identified, and show analogies with the classical vertebrate beds from the Latest Anisian and Early Ladinian at Monte San Giorgio in the Southern Alps. The vertebrate fauna must have been preserved in stagnant abiotic, probably anoxic bottom water conditions of a small restricted intraplatform basin. Dasycladacean algae are common allochthonous elements in these sediments, with *Diplopora annulata* as a typical species. At the top, regularly laminated limestones and dolomites grade into lagoonal dolomitic carbonates of the Altein Formation. These shallow marine carbonates contain abundant dasycladaceean *Diplopora annulata*.

The dominant carbonate sediments in the Middle Triassic of the Silvretta nappe are often interbedded with thin dark marlstones, suggesting a periodic influx of very fine siliciclastic material from an eroding continent. Several layers of carbonate-free shales, siltstones and sandstones show a conspicuous greenish to yellowish colour. They were found to be of volcaniclastic origin (discussion follows) and contain prismatic-euhedral zircon. Some of these layers are very thin and only visible in fresh outcrops, but thicker volcaniclastic beds are laterally traceable marker beds; e.g. in the Altein Formation.

Dolomite as well as evaporitic sediments (Mora cornieule) at the base of the Mingèr Formation are signs of an important regression. The upper part of this unit consists of stromatolitic peritidal dolomites and marls, interrupted by the siliciclastic marker bed of the Cluozza Member at the base of the Fanez Formation (Frank 1986). Based on palynological evidence, this interval could be assigned to the Early Carnian (Julian) (Hochuli & Frank 2000).The Cluozza Member can possibly be correlated with the Rheingrabner Wende in the Northern Calcareous Alps (Schlager & Schöllnberger 1974), dated as Late Julian by conodonts (Hornung 2006). Intertidal dolomites with a level of gypsum lenses (Stuls Member) and karstic collapse

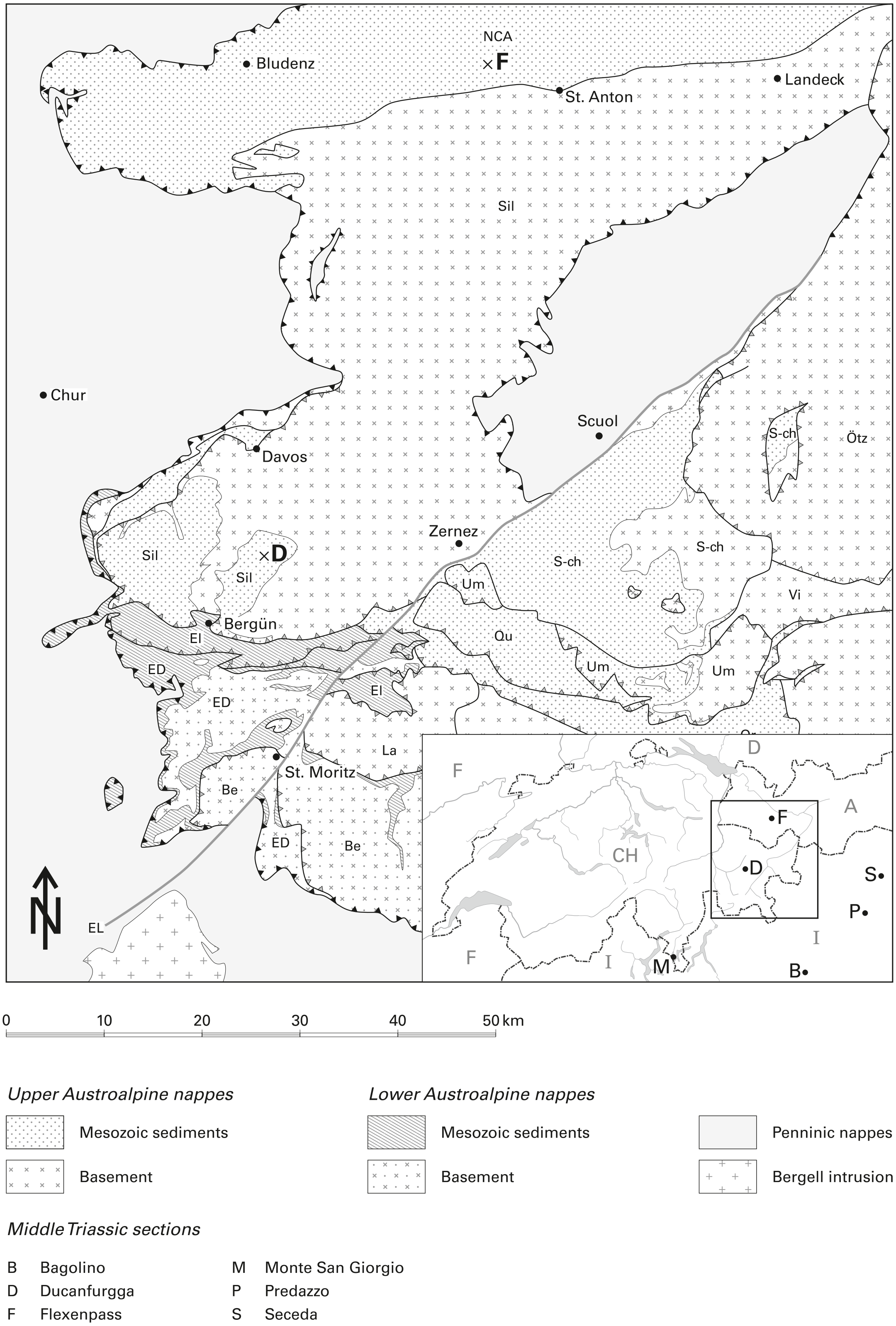


Fig. 1. Simplified geological map of the Austroalpine nappes in southeastern Switzerland (Graubünden), and localities of Middle Triassic sections in western Austria and northern Italy mentioned in the text (modified after Bundesamt für Landestopografie swisstopo 2005: Tektonische Karte der Schweiz 1 :500'000). Be: Bernina nappe; ED: Err complex; El: Ela nappe; EL: Engadine Line; La: Languard nappe; NCA: Lechtal nappe; Ötz: Ötztal nappe; Qu: Quattervals nappe; S-ch: Scharl nappe; Sil: Silvretta nappe; Vi: Vinschgau mylonite; Um: Umbrail–Chavalatsch slices.

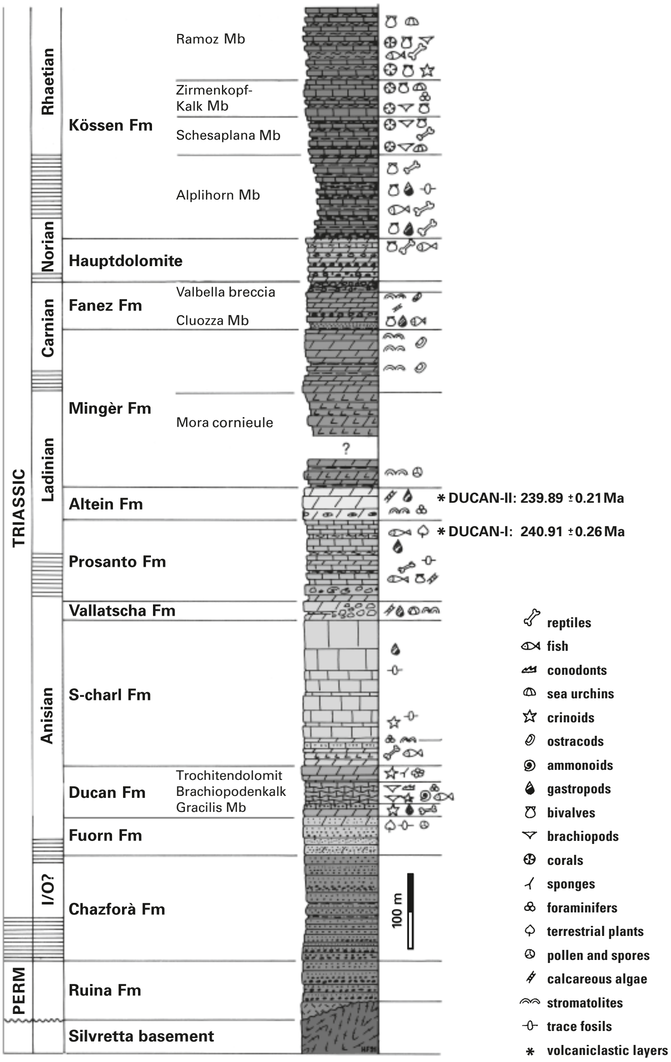


Fig. 2. Stratigraphic section of the Silvretta nappe at the Ducanfurgga near Davos (modified after Furrer et al. 1992).

breccias (Valbella breccia) document further regressions in the Late Carnian. The Latest Carnian to Norian Hauptdolomite is dominated by shallow water platform carbonates with rapid variations in thickness and facies over short distances: more than 800 m of sub- and intertidal dolomites with megalodontid bivalves at the south-western side (Gipshorn); less than 75 m of dolomites, breccias and soil horizons at the north-eastern side (Chrachenhorn and Alplihorn) over a distance of only 2 km, possibly due to differential subsidence along a synsedimentary fault (Furrer et al. 1992). At the end of the Triassic (Norian–Rhaetian), fine-grained siliciclastic sediments of the Kössen Formation were deposited in shallow basins, bordered by coral buildups, lagoons and tidal flats. Cyclic shale-marlstone-alternations typical of the basal member are frequently interbedded with biostromal coral banks. Locally thick reefal limestones and lagoonal limestones with megalodonts and the Rhaetian foraminifer *Triasina hantkeni* form thick lenticular carbonate bodies in the upper part of the Kössen Formation.

## U-Pb zircon geochronology

### *Rational and analytical techniques*

U-Pb age determinations utilizing isotope dilution thermal ionization mass spectrometry (ID-TIMS) applied to single grains of zircon yields the most precise and accurate results for dating volcanic ash layers and tuffs in stratigraphic successions (e.g. Mundil et al. 2001; Mundil et al. 2004; Condon et al. 2005). We assume that the zircon crystallization age closely approximates that of the volcanic eruption and ash layer deposition. Zircon is the preferred mineral for precise and accurate dating because it has the lowest diffusion coefficients for Pb (Cherniak & Watson 2001) and the highest resistance against post-crystallization system disturbances. Nevertheless, complications in getting precise and accurate zircon ages may arise from post-crystallization Pb loss and the incorporation of old cores acting as nuclei during crystallization, – or more generally – of foreign Pb with a radiogenic composition indicative for a pre-ash depositional age. To minimize the probability of inheritance only single zircon grains are selected for analyses, after microscopic inspection in transmitted light. Following the chemical abrasion (CA) technique of Mattinson (2005), all grains were subjected to high temperature annealing and HF leaching procedure, which recently proved to be more efficient in elimination of discordance caused by Pb loss (Mundil et al. 2004). Theoretically, successful application of CA technique ensures "closed system" behavior of the residual zircon and thus single grain analyses yielding a tight concordant cluster of Pb/U ages with precisions better than 0.1%. Complications may arise from small sample sizes, relatively low concentrations of U and young ages, resulting in low amounts of radiogenic Pb for analysis. This requires low analytical blanks and a good control on the blank isotopic composition.

### *Analytical techniques*

Zircons were prepared by standard mineral separation and purification methods (crushing and milling, concentration via Wilfley Table or hand washing, magnetic separation, and heavy liquids). Thermal annealing was performed by loading 20–40 zircon grains in quartz crucibles and placing them into a furnace at 850 °C for approximately 48 hours. The leaching step (chemical abrasion) was done in 3 ml screw-top Savillex vials with concentrated HF, placed in an oven at 180 °C for 15 hours. After the partial dissolution step the leachate was completely pipetted out and the remaining zircons were rinsed in 6N HCl, 4N $HNO_3$ and ultrapure $H_2O$. Single zircons were selected, weighed and loaded for dissolution into pre-cleaned miniaturized Teflon vessels. After adding a mixed $^{205}Pb$-$^{235}U$ spike zircons were dissolved in 63 µl concentrated HF with a trace of 7N $HNO_3$ at 180 °C for 7 days, evaporated and re-dissolved

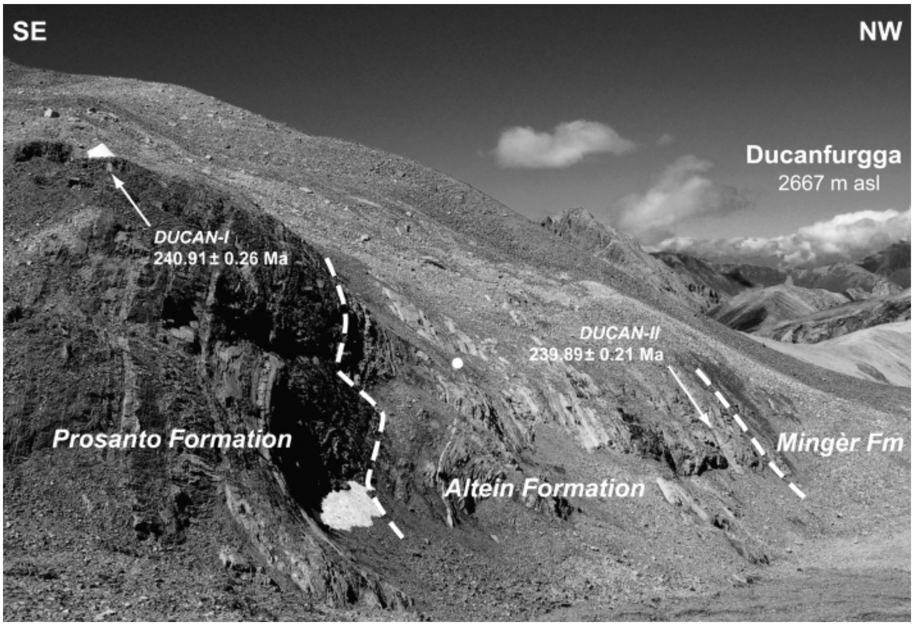


Fig. 3. View of the Middle Triassic section ESE of Ducanfurgga. The positions of the dated volcaniclastic layers DUCAN-I and DUCAN-II are indicated by arrows.

overnight in 36 µl 3N HCl at 180 °C. Pb and U were separated by anion exchange chromatography in 40 µl micro-columns, using minimal amounts of ultra-pure HCl, and finally dried down with 3 µl 0.2N or 0.06N $H_3PO_4$.

Isotopic analysis was performed on a TRITON mass spectrometer from Thermo/Finnigan equipped with a MasCom 19-dynode electron multiplier backed by a digital ion counting system. Linearity of the multiplier was established using the SRM987 standard solution (strontium) and controlled by U500 and Pb SRM982 measurements. Mass fractionation effects were corrected for 0.11 ± 0.05 per a.m.u. Both lead and uranium were loaded with 1 µl of silica gel-phosphoric acid mixture (Gerstenberger & Haase 1997) on outgassed single Re-filaments, and Pb as well as U (as $UO_2$) isotopes measured sequentially on the electron multiplier. Total procedural common Pb concentrations were estimated at values of 0.6 ± 0.2 pg and corrected with the following isotopic composition: $^{206}Pb/^{204}Pb$: 19.67 ± 0.23%, $^{207}Pb/^{204}Pb$: 16.63 ± 0.09%, $^{208}Pb/^{204}Pb$: 39.29 ± 0.15% (all 2σ uncertainties). Common lead concentrations in excess of blank lead were corrected for using the model of Stacey & Kramers (1975). The uncertainties of the spike and blank lead isotopic composition, mass fractionation correction, and tracer calibration were taken into account and propagated to the final uncertainties of isotopic ratios and ages. The PbMacDat program (Coleman, unpubl.) was used for age calculation and error propagation, which is using the algorithms of Ludwig (1980). The international R33 standard zircon (Black et al. 2004) is dated at an age of 419.10 ± 0.23 Ma (n = 17). Mean $^{206}Pb/^{238}U$ ages are given at the 95% confidence level. Ellipses plotted in concordia diagrams represent 2 sigma uncertainties (Ludwig 2005). The average concordant points of both samples are situated within the U decay constant uncertainties, but below the concordia line; this is in agreement with the findings of Schoene et al. (2006), suggesting that one or both U decay constants are systematically biased.

### *Dated volcaniclastic layers*

Two ash layers in the well exposed section ESE of Ducanfurgga have been sampled for radio-isotopic dating (Fig. 3). The older layer (DUCAN-I) in the upper part of the Prosanto Formation is only 10–15 mm thick and interlayered between dark laminated limestone beds, rich in well preserved small fish. The ash layer yields irregular patches or lenses of silt with zircon crystals of 0.1 mm length (Meister 1999). The second volcaniclastic layer (DUCAN-II) is 25 cm thick and is a yellow weathering marker bed in the upper part of the Altein Formation. It is the upper bed of the so called “double tuffs” (Frank 1986), forming the thickest of several ash layers consisting of illite, chlorite, biotite, volcanic quartz, sanidine and other feldspars, interpreted by Frank (1986) as originating from alkali rhyolite magmas.

### *Results* (analytical data in Table 1)

*DUCAN-I: Prosanto Formation:* U-Pb isotopic data of five out of six prismatic zircons (Fig. 4a) are concordant within analytical error and uncertainty of the U decay constants, and define a weighted mean $^{206}Pb/^{238}U$ age of 240.91 ± 0.26 Ma (MSWD = 0.28), which we consider the best estimate for the age of these zircons (and inferentially the deposition of the ash bed). Analysis 3 is discordant at a $^{206}Pb/^{238}U$ age of 249.3 Ma, pointing to an inheritance of probable Variscan age.

*DUCAN-II: Altein Formation:* Analysis of seven prismatic zircons crystals yielded a reproducible and concordant result with

Table 1. Isotopic results of U-Pb age determinations.

| Number | Weight [mg] | Concentrations | | | | Atomic ratios | | | | | | | Apparent ages | | | Error corr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | U | Pb rad. [ppm] | Pb nonrad. [pg] | Th/U a) | 206/204 b) | 207/235 c) | Error 2 s [%] | 206/238 c) d) | Error 2 s [%] | 207/206 c) d) | Error 2 s [%] | 206/238 d) | 207/235 | 207/206 d) | |
| **Tuff Prosanto Formation (DUCAN-I)** | | | | | | | | | | | | | | | | |
| 2 | 0.0029 | 358 | 14.10 | 0.65 | 0.46 | 3977 | 0.2685 | 0.26 | 0.03807 | 0.24 | 0.05115 | 0.11 | 240.9 | 241.5 | 247.6 | 0.90 |
| 3 | 0.0037 | 392 | 16.23 | 0.77 | 0.54 | 4855 | 0.2790 | 0.25 | 0.03942 | 0.23 | 0.05133 | 0.09 | 249.3 | 249.8 | 255.7 | 0.93 |
| 4 | 0.0012 | 246 | 9.93 | 0.54 | 0.56 | 1381 | 0.2683 | 0.36 | 0.03804 | 0.27 | 0.05114 | 0.22 | 240.7 | 241.3 | 247.1 | 0.79 |
| 5 | 0.0020 | 551 | 21.86 | 1.03 | 0.50 | 2646 | 0.2679 | 0.24 | 0.03807 | 0.23 | 0.05103 | 0.08 | 240.9 | 241.0 | 242.2 | 0.94 |
| 7 | 0.0034 | 458 | 17.89 | 0.63 | 0.44 | 6206 | 0.2680 | 0.25 | 0.03808 | 0.23 | 0.05105 | 0.08 | 240.9 | 241.1 | 243.1 | 0.95 |
| 8 | 0.0023 | 446 | 17.48 | 0.56 | 0.45 | 4581 | 0.2684 | 0.25 | 0.03811 | 0.23 | 0.05106 | 0.09 | 241.1 | 241.4 | 243.6 | 0.93 |
| **Tuff Altein Dolomite (DUCAN-II)** | | | | | | | | | | | | | | | | |
| 2 | 0.0084 | 343 | 13.64 | 2.06 | 0.53 | 3448 | 0.2668 | 0.26 | 0.03790 | 0.23 | 0.05104 | 0.11 | 239.8 | 240.1 | 242.6 | 0.91 |
| 3 | 0.0058 | 187 | 7.49 | 1.85 | 0.56 | 1451 | 0.2664 | 0.30 | 0.03790 | 0.23 | 0.05098 | 0.18 | 239.8 | 239.8 | 239.9 | 0.80 |
| 4 | 0.0061 | 242 | 9.62 | 1.23 | 0.51 | 2981 | 0.2670 | 0.32 | 0.03789 | 0.24 | 0.05110 | 0.20 | 239.8 | 240.3 | 245.3 | 0.77 |
| 5 | 0.0032 | 373 | 15.11 | 1.23 | 0.60 | 2377 | 0.2666 | 0.25 | 0.03794 | 0.23 | 0.05096 | 0.10 | 240.1 | 240.0 | 239.0 | 0.92 |
| 6 | 0.0035 | 434 | 17.35 | 1.01 | 0.54 | 3693 | 0.2667 | 0.25 | 0.03791 | 0.23 | 0.05101 | 0.09 | 239.9 | 240.0 | 241.3 | 0.93 |
| 7 | 0.0035 | 468 | 18.88 | 1.62 | 0.58 | 2477 | 0.2666 | 0.25 | 0.03792 | 0.23 | 0.05098 | 0.09 | 240.0 | 239.9 | 239.9 | 0.93 |
| 8 | 0.0080 | 288 | 11.48 | 1.29 | 0.54 | 4401 | 0.2667 | 0.24 | 0.03791 | 0.23 | 0.05102 | 0.07 | 239.9 | 240.1 | 241.7 | 0.96 |

a) Calculated on the basis of radiogenic $^{208}Pb/^{206}Pb$ ratios, assuming concordancy. b) Corrected for fractionation and spike. c) Corrected for fractionation, spike, blank and common lead (according to Stacey and Kramer, 1975). d) Corrected for initial 230Th disequilibrium, with Th/U (source) = 4.

a mean $^{206}Pb/^{238}U$ age of 239.89 ± 0.21 Ma (MSWD = 0.13), interpreted as the age of zircon crystallization and deposition of the tuff (Fig. 4b).

## Significance of the new age determinations

The precise age determinations agree with their stratigraphic succession and allow the stratigraphic age difference between the two volcaniclastic layers to be resolved. With the $^{206}Pb/^{238}U$ age of 240.91 ± 0.26 Ma for the volcanic ash layer in the upper part of the Prosanto Formation, a first precise age of its rich marine vertebrate fauna is available. The second layer in the Altein Formation with a $^{206}Pb/^{238}U$ age of 239.89 ± 0.21 Ma is situated 80 m higher in the section of platform carbonates. These $^{206}Pb/^{238}U$ ages demonstrate that the upper Prosanto Formation and the Altein Formation are of Early Ladinian age and clearly older than suggested by Eichenberger (1985) and Furrer et al. (1992, 1995). The time interval bracketed by these two volcanic ashes is 1.02 ± 0.47 m.y., indicating an average sedimentation or accumulation rate of 80 m/m.y., a reasonable value for lagoonal and platform carbonate sedimentation (Schlager 1999). It is obvious that the accumulation rate in such an intra platform depression was higher than in the basinal sediments of the Buchenstein Formation in the western and central Dolomites with values around 8 m/m.y. (Brack et al. 2007).

## Correlation within the South Alpine and Austroalpine units

Our data allow a direct correlation of the upper Prosanto Formation and Altein Dolomite within the Upper Austroalpine Silvretta nappe with the section at Bagolino (Eastern Lombardy, northern Italy), containing the Global boundary Stratotype Section and Point (GSSP) for the base of the Ladinian stage (Brack et al. 2005). This and correlated sections are calibrated by numerous U-Pb age determinations from different laboratories (see discussion in Brack et al. 2005, 2007). When comparing our new annealed-leached U-Pb age determinations, we have to refer to the data of Brack et al. (2007, Fig. 11) obtained with refined annealing-leaching technique. Considering an age of 242 Ma to be correct for the base of the Ladinian stage in the GSSP section at Bagolino, we can infer an earliest Ladinian age for the upper Prosanto Formation, which is therefore a time equivalent of the middle part (in particular the Middle Pietra Verde) of the Southern Alpine Buchenstein Formation (Fig. 5). The Altein Formation was deposited in the early Ladinian as well and we tentatively correlate it with the upper part of the Buchenstein Formation. Despite the high precision of the U-Pb age determinations, it is not possible to indicate the biozone, as the zonation in the early Ladinian is still under discussion (Brack et al. 2007)

Based on the new age constraints, the upper Prosanto Formation and the Altein Formation are also time equivalents of the San Giorgio Formation and the lower Meride Formation at Monte San Giorgio (Wirz 1945, Furrer 1995), because the Anisian-Ladinian boundary could be localized in the uppermost part of the underlying Besano Formation (Brack et al. 2005, Fig. 7). A volcanic ash bed in the middle part of underlying Besano Formation (Grenzbitumenzone) yielded a U-Pb-zircon-age of 241.2 ± 0.8 Ma (Mundil et al. 1996, Brack et al. 2005), a minimum age, that must be about 1 m.y. older (Brack et al. 2007). It is not yet clear whether the rich vertebrate fauna from the upper Prosanto Formation is a time equivalent of the

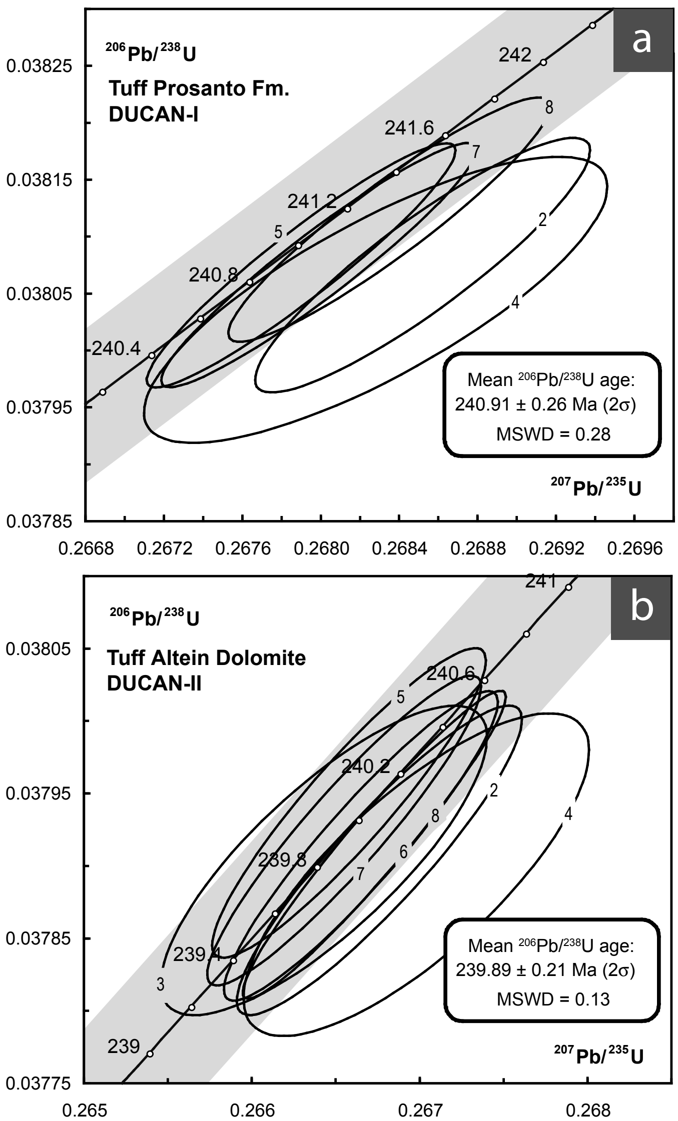


Fig. 4. Concordia diagrams showing the results of U-Pb age determination: (a) DUCAN-I (Prosanto Formation; b) DUCAN-II (Altein Formation).

three vertebrate faunas in the lower Meride Formation (Cava inferiore, Cava superiore and Cassina beds, Furrer 1995). A thick volcaniclastic layer in the Cava inferiore beds from Val Serrata was dated by Hellmann & Lippolt (1981) to an age of 225 ± 2 Ma (Ar-Ar-age on sanidine), the precision and accuracy of which would have to be reassessed. The occurrence of several specimens of the ammonoid *Arpadites* sp. below and above the Val Serrata volcaniclastic layer at Monte San Giorgio (Schatz 2005, and new material collected by H. Furrer, determined by H. Rieber) correlates with *Arpadites* specimens below and above the dated volcaniclastic layer (Earliest Ladinian) in the Buchenstein Formation in the GSSP section at Bagolino (Brack et al. 2005, Fig. 7).

The volcaniclastic layer in the Altein Formation is older than the U-Pb-zircon-age of the Predazzo granite, cutting the Ladinian Buchenstein and Wengen Formations (minimum age 237.3 + 0.4/–1.0 Ma in Brack et al. 1997).

The correlation of the Middle Triassic sequences of the Silvretta nappe and the Northern Calcareous Alps, both deposited in the Upper Austroalpine realm, is difficult because good index fossils or marker beds are missing. The Reifling beds of the western Lechtal nappe have been placed at the Anisian-Ladinian boundary by means of rare and incorrectly determined brachiopods, daonellas, ammonoids and conodonts (Hirsch 1966, Kobel 1969). A first U-Pb age of 239.3 ± 0.2 Ma for a volcaniclastic layer in the upper Reifling beds at Flexenpass (Austria) by Brühwiler et al. (2007) allows a good correlation with the volcaniclastic layers in the Silvretta nappe. As the volcaniclastic layer in the upper Altein Formation is somewhat older than the dated volcaniclastic layers in the upper Reifling beds, the basinal Reifling beds are at least in part age equivalents of the lagoonal Altein and Prosanto Formation.

## Conclusions

The new U-Pb ages of 240.91 ± 0.26 Ma and 239.89 ± 0.21 Ma from two volcaniclastic layers within the carbonate platform sequence in the Ducan area provide the opportunity to (1) precisely constrain an interval of carbonate sedimentation, (2) infer the stratigraphic position of these fossil-poor rocks, and (3) compare the studied section to other time-series records in Austroalpine or Southalpine units. Because available ages for different sections are usually produced in different laboratories (using different U-Pb tracer solutions), testing their accuracy in an absolute and relative time-frame requires high-precision intercalibration between the different laboratories (see Condon et al. 2005). Furthermore, testing the accuracy and significance of these dates in terms of the paleontologic, biostratigraphic and paleo-environmental record requires the intercalibration of multiple well-calibrated marine sections, preferably including the GSSP of this time period. Intercalibration of stratigraphic sections using a combination of geochronologic, bio-, chemo- and lithostratigraphic techniques is the best way to infer absolute rates of sedimentary, environmental and biotic processes in Earth's history.

The precise age determination of the volcaniclastic layer in the upper Prosanto Formation (Earliest Ladinian) documents that its rich marine vertebrate fauna is definitively younger than the classical fauna of the Besano Formation (Latest Anisian to Earliest Ladinian) at Monte San Giorgio, though they share some fish taxa. But it is not yet clear whether the fauna from the upper Prosanto Formation is a time equivalent of the three vertebrate faunas in the lower Meride Formation. A new U-Pb age determination of the thick volcaniclastic layers in the Cava inferiore beds could resolve this problem.

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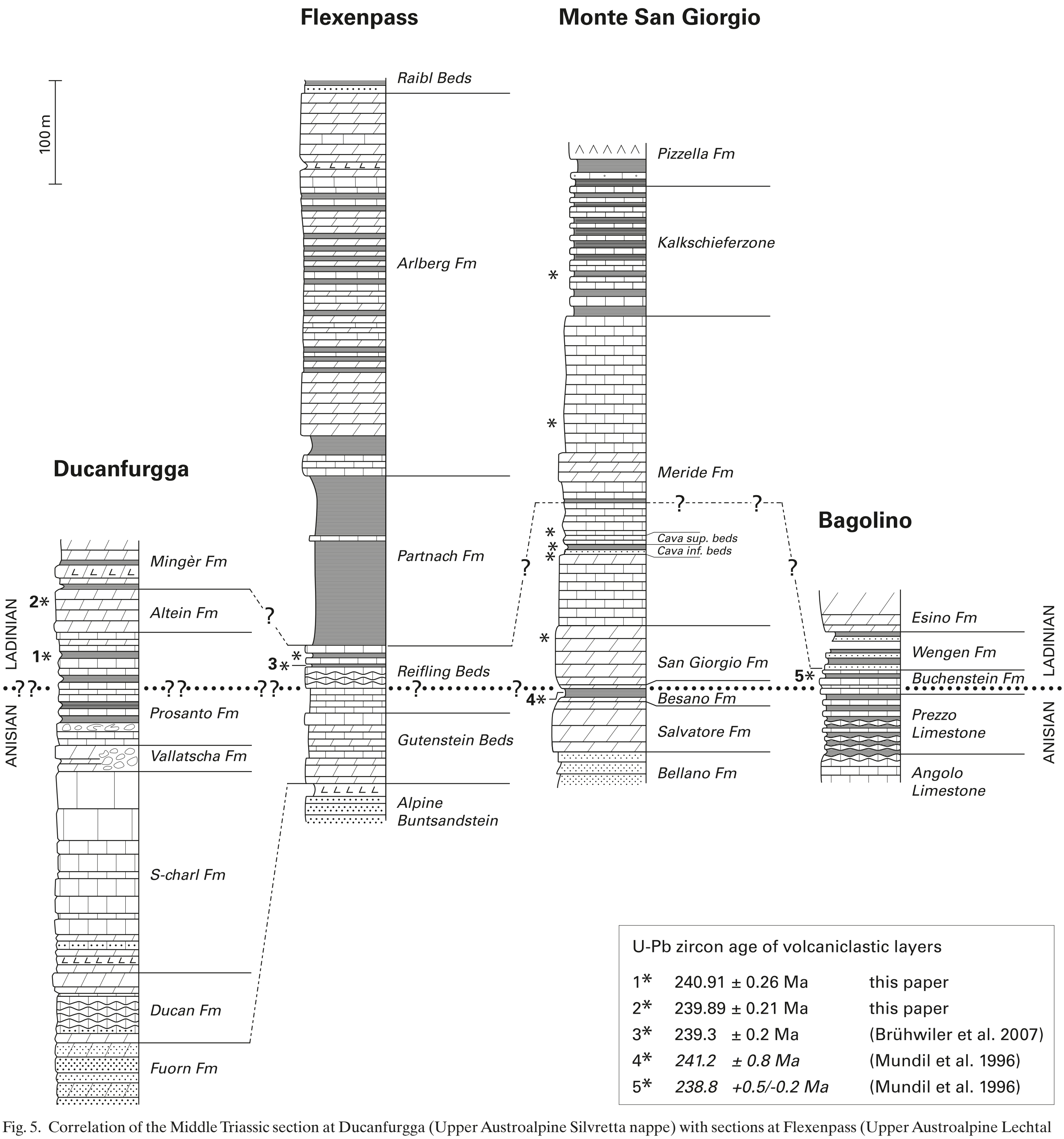


Fig. 5. Correlation of the Middle Triassic section at Ducanfurgga (Upper Austroalpine Silvretta nappe) with sections at Flexenpass (Upper Austroalpine Lechtal nappe, after Hirsch 1966 and Brühwiler et al. 2007), at Monte San Giorgio (western Southern Alps), and the GSSP-section for the base of the Ladinian stage at Bagolino (Southern Alps; after Brack et al. 2005). Brack et al. (2007) suggested that the old U-Pb ages of 4 and 5 (in italics) measured by Mundil et al. (1996) may be approximately 1 m.y. too young due to different sample preparation techniques (see text for further explanation).

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